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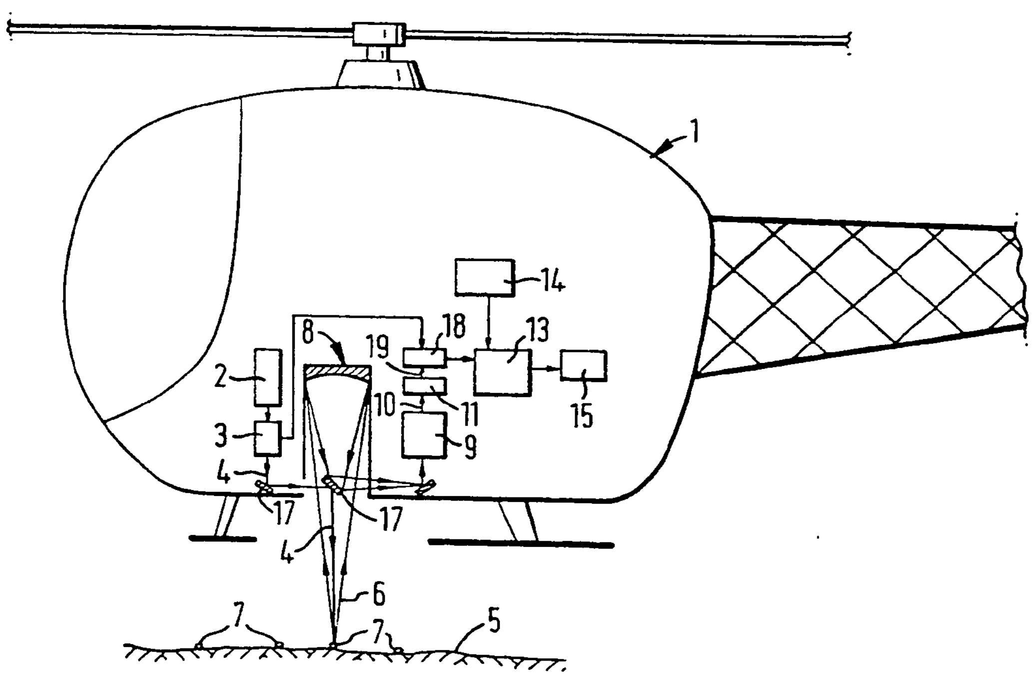
(54) **Exploration method**

(57) A method of exploring for diamonds by irradiating ground suspected of containing diamondiferous material, for example micro-diamonds, with laser radiation, preferably modulated or pulsed, from an airborne laser and detecting the resultant scattered Raman radiation characteristic of diamond by means of an airborne detector. A map of the location of the materials can be prepared by measuring the intensity of the radiation with respect to the ground.



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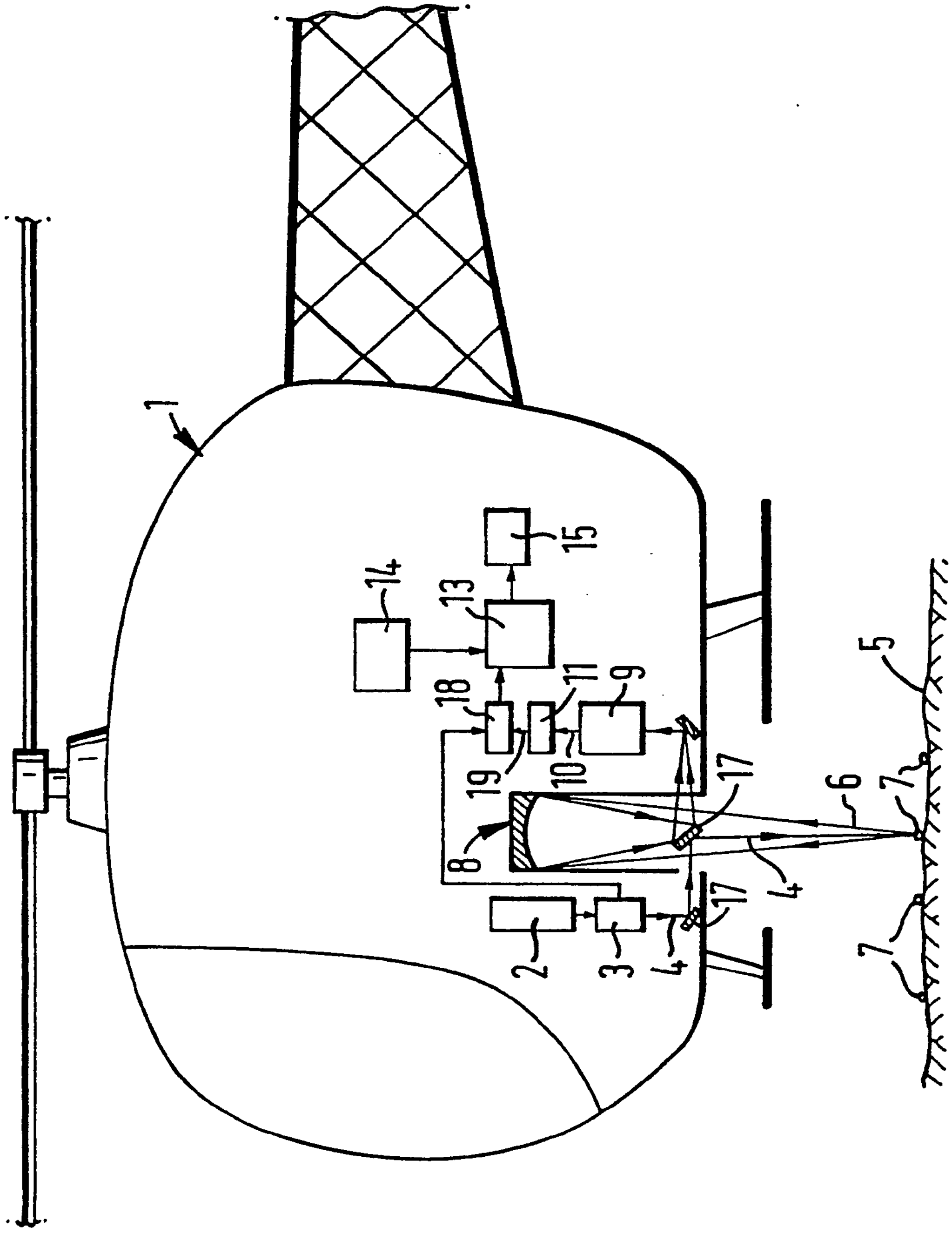
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EXPLORATION METHOD

This invention relates to an exploration method and in particular to a method of exploring for diamonds using airborne apparatus.

Micro-diamonds are very small diamonds, typically up to 0.5 millimetre across which may be found in the ground in areas where deposits of larger diamonds may be found. Micro-diamonds are often distributed over a wide area and may be used as pathfinders for the larger diamond deposits. However, exploration of large areas and broad surveying for micro-diamonds has hitherto been painstakingly labour intensive because of their small size and the current difficulty in detection.

The Raman signal of diamond is stronger than that of most other materials because diamond only contains carbon to carbon bonding and its Raman signal occurs at a position well separated from those of other minerals. Also, because diamond only contains one type of carbon to carbon bond, there is only a single Raman signal, which is readily distinguishable from associated broad band fluorescence. Raman spectroscopy may be used for detecting diamonds in locations which are not easily accessible and is disclosed in our PCT patent application no. WO88/07213.

It has been found that a continuous, modulated or pulsed source of laser radiation and a detector are particularly suitable for selectively determining the presence of Raman-active material such as diamonds or micro-diamonds which may be exposed to laser radiation from a distance for only a short time period, for example

in an exploration method. It has also been surprisingly found that this determination may be performed remotely using an airborne source of laser radiation and an airborne detector.

Thus according to the present invention there is provided a method of exploring for diamonds comprising the steps of (a) irradiating ground suspected of containing diamondiferous material with laser radiation of pre-determined wavelength and capable of causing Raman radiation to be scattered from diamondiferous material on the ground, by means of an airborne source of laser radiation and (b) detecting the scattered Raman radiation characteristic of diamond by means of an airborne detector whereby the presence of diamondiferous material on the ground may be determined.

Diamondiferous material is material containing diamonds and may comprise diamonds, micro-diamonds, diamond dust and the like. Diamondiferous material on the ground means diamondiferous material on or in the ground. The ground may be on land or may be covered by water, for example a river bed or sea bed.

The laser radiation may be provided by a continuous-wave laser with constant intensity. Preferably, the laser radiation may have an intensity which varies with time, for example modulated or pulsed laser radiation. The laser radiation may be provided by a modulated or chopped, continuous-wave laser. The intensity of the radiation may vary in the form of a sine wave or square wave or may be pulsed. The laser radiation may be provided by a pulsed laser, for example an ultra-violet excimer, a visible metal gas discharge laser, a flash lamp-pumped laser or a semi-conductor pumped solid-state laser. Such lasers may be Nd-YAG lasers or ruby laser or pulsed argon ion lasers. The pulsed lasers may have nanosecond or picosecond pulse widths. The picosecond pulsed lasers may comprise a source laser, a synchronously pumped, cavity dumped, dye laser with amplifiers and further wavelength shifting units. The lasers may have regenerative amplifier and wavelength shifting units. It is envisaged that regenerative amplification systems with high repetition rate may be included in the picosecond source of laser radiation.

The laser radiation may have any wavelength suitable for the application. For exploration in clear ocean water the laser radiation is preferably blue, tending towards yellow/red for coastal regions and river bottoms as turbidity increases.

The scattered Raman radiation may be collected by a collection system which may comprise lenses or focussing mirrors in a telescopic arrangement.

The detector may comprise a dispersing spectrograph or an optical filter or filters together with a photodetector. The photodetector may comprise a gateable multichannel diode array photodetector, a charge coupled device detector or a gated photomultiplier tube detector. Preferably the detector should be synchronised with the modulation or pulsing of the laser if laser radiation with time-varying intensity is used. With a modulated laser, correction may be made for phase shift resulting from the delay between irradiating the ground and detecting the Raman radiation at a distance. With a pulsed laser, range gating may be used to reduce noise and back-scattered radiation interference. Preferably, the intensity of the detected radiation is measured by a microprocessor which determines the presence or otherwise of diamondiferous material. For example, the intensity of the detected Raman radiation may be measured and the intensity of radiation which is not characteristic of diamond for example, background fluorescence may be subtracted so as to determine the presence of diamondiferous material.

The laser and the detector may be mounted in a helicopter, aeroplane, airship or the like. The method may be used over land, sea or riverbeds.

The presence or otherwise of diamondiferous material may be recorded photographically, electronically and the like, together with positional information. The microprocessor may generate a map of the location of diamondiferous material.

The invention will now be described by way of example only and with reference to the accompanying drawing which represents in schematic form a helicopter having apparatus for use in the method

of the present invention for exploring for diamonds.

The helicopter (1) has a source (2) of laser radiation (4) which is a continuous wave laser, for example an argon ion laser operating at 514.5 nanometres wavelength. The laser radiation (4) is modulated sinusoidally by an extra-cavity, accousto-optic amplitude modulator (3) operating at 10MHz. The beam (4) of laser radiation is directed at the ground (5) by mirrors (17). The laser radiation (4) is capable of causing Raman radiation (6) to be scattered by diamondiferous material (7) on the ground (5). The helicopter (1) has a telescope (8) which collects the scattered Raman radiation (6) and passes it to a spectral analyser (9) which disperses the Raman radiation (6) into its constituent spectrum (10) and has sufficient resolution to allow radiation characteristics of diamond to be detected. A photodetector array (11) is synchronised with the modulator (3) and is capable of detecting the dispersed radiation (10). The detector (11) may be synchronised by passing the signal (19) generated by the detector (11) into a phase-sensitive lock in amplifer (18) operating at the same frequency as the modulation of the laser radiation. The photodetector is connected to a microprocessor (13) which receives navigation data (14) and can generate a map (15) showing the presence of microdiamonds (7).

In use, the helicopter (1) flys over the ground (5) to be explored. A beam (4) of modulated radiation from the laser (2) is directed at the ground by the mirrors (17), the laser radiation (4) being capable of causing Raman radiation (6) to be scattered from diamondiferous material (7) on the ground (5). The scattered Raman radiation (6) is collected by the telescope (8) and is passed through the spectral analyser (9) which disperses the Raman radiation (6) into its constituent spectrum (10). The photo detector array (11) which is synchronised with and phase-sensitive to the modulator (3), detects Raman radiation characteristic of diamond and background radiation in the dispersed radiation (10). The microprocessor (13) measures the time-varying intensity of the detected radiation, subtracts the background radiation and combines

this with the navigation data (14) to produce a map (15) showing the location of diamondiferous material.

In another example, which might be used for a fixed wing aircraft the telescope (8) may compromise a steerable mirror (not shown) which permits the ground to be scanned in a line, the output from the detector (11) being analysed by the microprocessor (13) in a similar manner but with output onto a line scan synchronised, charge-coupled device (CCD) camera outputting to a frame storage and image analysis computer (not shown).

Claims:

1. A method of exploring for diamonds comprising the steps of (a) irradiating ground suspected of containing diamondiferous material with laser radiation of pre-determined wavelength and capable of causing Raman radiation to be scattered from diamondiferous material on the ground, by means of an airborne source of laser radiation and (b) detecting the scattered Raman radiation characteristic of diamond by means of an airborne detector whereby the presence of diamondiferous material on the ground may be determined.

2. A method of exploring for diamonds according to claim 1 in which the intensity of the laser radiation varies with time.

3. A method of exploring for diamonds according to claim 2 in which the detector is synchronised with the time-varying intensity of the laser radiation.

4. A method of exploring for diamonds according to claim 2 in which the laser radiation is pulsed.

5. A method of exploring for diamonds according to claim 4 in which the detector is range gated with the pulsed laser radiation.

6. A method of exploring for diamonds according to any one of the preceding claims in which Raman radiation scattered from diamondiferous material on the ground is collected by means comprising a telescope.

7. A method of exploring for diamonds according to any one of the preceding claims in which the intensity of the detected Raman radiation characteristic of diamond is measured by means comprising a microprocessor which determines the presence or otherwise of

diamondiferous material.

8. A method of exploring for diamonds according to claim 7 in which the microprocessor selectively rejects background fluorescence.

9. A method of exploring for diamonds according to any one of the preceding claims in which the diamondiferous material comprises micro-diamonds.

10. A method of exploring for diamonds substantially as herebefore described and with reference to the drawing.

11. A method of producing a map of the location of diamondiferous material comprising the steps of (a) irradiating ground suspected of containing diamondiferous material with laser radiation, of pre-determined wavelength and capable of causing Raman radiation to be scattered from diamondiferous material on the ground, by means of an airborne source of laser radiation, (b) detecting the scattered Raman radiation characteristic of diamond by means of an airborne detector, and (c) measuring the intensity of the detected radiation according to the position of the airborne detector with respect to the ground.

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